Reprinted from *Agronomy Journal*
Vol. 74, March-April 1982, p. 389-395

Planting Date Effects on Sunflower Head and Seed Development[1]

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ABSTRACT

The effects of environmental conditions during sunflower (*Helianthus annuus* L.) seed development and maturation on the final oil percent of seed and composition of the oil have been studied extensively but little is known about the sequential changes that occur in seed and oil during seed development and maturation. A better understanding of these changes could lead to improved management of sunflower for seed and oil production. The objective of this study was to determine the influence of planting date on development and maturation of sunflower head and seed. Sunflower was planted in about 2-week intervals from 23 Mar. to 1 Aug. 1977 in field plots on Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls). The experiment had a randomized block design with three replications. Plants that were at the same stage of development were marked at the ray flower stage. After anthesis, head samples were collected two or three times each week for about 30 days to determine head weight and diameter; seed dry matter percent, weight, and oil percent; and oleic and linoleic acid concentration of the oil. Separate seed samples were obtained from the outer, middle, and inner sections of the heads. Planting date, sampling date, and head position, as well as the interactions of these variables, significantly affected all dependent variables. Head diameter and fresh weight initially increased as the sunflower developed, then decreased due to head shrinkage and drying as the sunflower matured. Seed dry matter percent increased from the first to last sampling, but not at the same rate for all planting dates. Trends for seed weight were similar to those for dry matter. Total oil percent of seed increased from the first to the seventh sampling after which the differences were not significant. Seed from late plantings generally had a low oil percent, but seed from the ninth planting had an unexplained high oil percent. Oleic and linoleic acid concentrations of the oil decreased and increased, respectively, for later plantings. These trends also occurred with later samplings of sunflower planted on a given date. Based on multiple regressions, air temperature significantly influenced changes per day in seed oil percent, but not the oleic and linoleic acid concentration of the oil, during the intervals between samplings. During these intervals, changes in oleic and linoleic acid concentration of the oil were significantly influenced by total solar radiation and daylength.

***Additional index words:* *Helianthus annuus* L., Oleic acid, Linoleic acid.**

ENVIRONMENTAL factors, especially temperature during the period of seed development and maturation, affect oil percent and composition of mature seed of sunflower (*Helianthus annuus* L.). The effect of temperature on seed oil percent, however, has been variable. Robertson et al. (1979) found that latitude and average temperature from the full-bloom stage to harvest of field-grown sunflower did not significantly affect oil percent of seed obtained from 22 locations in 1976 and 35 locations in 1977 in North America. However, Canvin (1965) found that sunflower grown at a constant temperature of 21 C had a higher oil percent than those grown at either a lower or higher temperature. Downes (1974) and Harris et al. (1978) showed that oil percent decreased as temperature increased. In contrast, Johnson and Jellum (1972) and Unger (1980) found that the oil percent of seed from late-planted sunflower maturing during cooler weather was lower than from earlier-planted sunflower maturing during warmer weather. These different responses may have been due to temperature effects at specific developmental stages or to factors other than temperature.

The fatty acid concentration of sunflower oil is strongly influenced by temperature during seed development (Canvin, 1965; Harris et al., 1978; Keefer et al., 1976; Robertson et al., 1979; Unger, 1980). Seed maturation during periods of high temperature results

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in oil with high and low concentrations of oleic and linoleic acids, respectively. Seed maturation during periods of low temperatures gives opposite results. Whether the effects are solely due to temperature has not been determined. Oleic and linoleic acids comprise about 85 to 90% of the oil of sunflower. The remainder is comprised mainly of palmitic and stearic acids (Robertson et al., 1979) and minor amounts of myristic, palmitoleic, hexadecadienoic, linolenic, arachidic, and gadoleic acids.

Although the effect of environmental conditions during sunflower seed development and maturation on oil percent and oleic and linoleic acid concentration of oil of mature seed has been studied rather extensively, relatively little is known about the changes that occur in seed during development and maturation. In Australia, sunflower seed that developed when the mean daily temperature was above 15 C accumulated dry matter, oil, oleic acid, and linoleic acid more rapidly than when the mean temperature was below 15 C (Anderson, 1975). The maxima for oil percent and oil constituents were reached at about the same time as that for dry matter. Anderson (1975) concluded that sunflower reached physiological maturity at about the time at which the maxima for any of the above factors was reached. He realized, however, that the results may have been different under other environmental conditions, mainly different temperatures. A better understanding of the changes that occur in sunflower seed during development and maturation over a wide range of environmental conditions would permit a more accurate determination of physiological maturity and would be valuable for managing sunflower with respect to time of planting and irrigating. The objective of this study was to determine the influence of planting dates on the development and maturation of sunflower head and seed. Use of different planting dates resulted in seed development and maturation during periods of widely differing temperature, solar radiation, and daylength.

MATERIALS AND METHODS

Sunflower from which the samples for this study were taken was grown on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) in 1977 at Bushland, Texas, which is at 35° 11′ N Lat and 102° 5′ W Long. Elevation of Bushland is 1,180 m, and the average dates of last and first frost are 18 April and 28 October, respectively.

'Hybrid 896' sunflower was planted on dates shown in Table 1 to obtain about 64,000 plants/ha. The sunflower was furrow-irrigated for uniform emergence and as necessary during the growing season to avoid afternoon wilt. Samples for this study were taken in 1977; other details of the 4-year planting date study from which they were taken are reported elsewhere (Unger, 1980).

When plants had ray flowers showing (very late budding) or starting to open (very early flowering), about 45 plants in each of three replications were marked with plastic ribbon. All selected plants of a given planting were marked on the same day. Sampling for determining head and seed development was started when disk flowering (anthesis) neared completion for plants of a given planting. Additional samples were obtained two or three times each week for about 30 days.

At each sampling for a given planting, three heads were randomly selected from each replication for determining their diameter and fresh weight. Subsequently, separate seed samples were taken from inner, middle, and outer ring-shaped zones of the heads. Each zone represented one-third of the radius from the center to the outer edge of the heads. Determinations made on seed were dry matter percent, weight, total oil percent, and oleic and linoleic acid concentrations of the oil. Seed was oven-dried at 100 C before determining weight per seed (based on 100 seeds) and oil percent. Oil percent was determined by the nuclear magnetic resonance (NMR) technique (Granlund and Zimmerman, 1975). Oleic and linoleic acid concentrations in oil were estimated by the refractive index method (Goss, 1978). Data were analyzed by analysis of variance.

Temperature, solar radiation, and net radiation (over a short grass sod) were measured at a weather station about 2.5 km from the sunflower plot area. Average daily maximum, minimum, and mean temperature; total and net solar radiation; and daylength during the intervals between samplings were independent variables in simple and multiple linear regression analyses for determining which factors were significantly associated with changes per day in seed weight, oil percent, and oleic and linoleic acid concentrations of oil between samplings (until a maximum or minimum occurred for a particular factor). The effects of independent variables on seed oil percent and oleic and linoleic acid concentration of the oil were analyzed on percent and weight per seed bases. Besides partial regression coefficients and the correlation coefficient (R), standardized partial regression coefficients were also calculated (Ezekiel and Fox, 1959; Steel and Torrie, 1960). Based on the standardized coefficients, the independent variables were ranked in order of their relative importance for influencing the various seed characteristics. All variables were used in the initial analysis. In subsequent analyses, the lowest ranking variable was sequentially excluded, which resulted in the final analysis being a simple linear regression analysis.

RESULTS AND DISCUSSION

Average values of the various head and seed factors for the different plantings, samplings, and head areas are shown in Table 1. The statistical analyses of the data are summarized in Table 2. Detailed data for seed and oil factors as influenced by planting dates, sampling dates, and head areas are illustrated in Fig. 1 to 4. The figures, in general, illustrate that sunflower for the first two plantings developed at about the same time and rate, even though the plantings were made 2 weeks apart. Also illustrated is the delayed time and rate of development for sunflower of the tenth planting.

Head Diameter and Fresh Weight

Although statistically significant, head diameters due to planting dates showed no definite trends. Heads were largest for the 19 June planting and smallest for the 4 July planting (Table 1). Head sizes probably were influenced by plant population differences, which were not determined, and by natural plant variability. Average head diameters for sequential samplings initially increased, reached a maximum for the fourth and fifth sampling, and then usually decreased until the final sampling. The initial increases resulted from growth and head development. Later decreases resulted from shrinkage as the sunflower approached maturity.

Average fresh weights of heads showed no definite trends due to planting date (Table 1), and were affected by head diameter. The relationship between

Table 1. Effect of planting date, sampling number, and head zone on various sunflower head and seed factors.

Planting No.	Date	Head diam.	Head fresh weight	Seed dry matter	Weight per seed	Total oil	Oleic acid	Linoleic acid	Oleic acid	Linoleic acid
		mm	g	%	mg	%			mg/seed	
1	23 Mar.	170 b†	410 ab	39.4 d	38.9 ab	34.9 b	58.6 a	25.3 g	8.0	3.4
2	6 Apr.	170 b	380 bc	42.7 c	38.2 ab	36.7 a	55.1 b	29.4 f	7.7	4.1
3	25 Apr.	160 c	340 cd	41.3 c	36.4 bc	34.1 b	54.0 b	31.3 f	6.7	3.9
4	9 May	170 b	420 ab	41.3 c	38.1 ab	35.4 ab	49.4 c	36.9 de	6.7	5.0
5	23 May	160 c	270 de	45.4 b	34.0 cd	32.0 c	49.7 c	36.2 e	5.4	3.9
6	6 June	170 b	340 cd	46.4 b	33.2 d	34.8 b	47.0 d	39.7 cd	5.4	4.6
7	19 June	180 a	450 a	45.5 b	39.1 ab	31.4 c	46.9 d	39.9 c	5.8	4.9
8	4 July	150 d	250 e	41.9 c	37.4 b	24.3 d	44.7 d	42.5 c	4.1	3.9
9	18 July	170 b	310 de	48.7 a	40.7 a	35.6 ab	27.5 f	63.7 a	4.0	9.2
10	1 Aug.	170 b	360 cd	27.8 e	24.6 e	23.2 d	30.6 e	60.1 b	1.7	3.4
Sampling no.										
1		160 c	360 b	13.8 j	13.7 h	4.3 g	–	–	–	–
2		170 b	420 a	16.5 i	18.7 g	11.0 f	–	–	–	–
3		170 b	440 a	21.6 h	24.5 f	20.6 e	–	–	–	–
4		180 a	450 a	27.0 g	29.8 e	28.9 d	56.7 a	28.0 e	4.9	2.4
5		180 a	410 a	35.6 f	37.3 d	37.7 c	52.1 b	33.4 d	7.3	4.7
6		160 c	350 bc	44.9 e	40.8 c	42.1 b	47.2 c	39.4 c	8.1	6.8
7		170 b	330 bc	52.8 d	45.5 b	44.1 a	45.1 d	42.2 b	9.0	8.5
8		170 b	310 c	59.9 c	49.1 a	45.2 a	43.4 d	44.1 b	9.6	9.8
9		160 c	240 d	72.5 b	50.0 a	44.0 a	40.5 e	47.6 a	8.9	10.5
10		150 d	220 d	75.6 a	51.2 a	44.5 a	39.5 e	48.8 a	9.0	11.1
Head zone										
Outer		–	–	46.3 a	44.3 a	34.2 a	45.7 b	41.4 a	6.9	6.3
Middle		–	–	43.1 b	37.5 b	33.3 b	45.6 b	41.5 a	5.7	5.2
Inner		–	–	36.3 c	26.3 c	29.2 c	47.9 a	38.7 b	3.7	3.0

† Values within a group followed by the same letter or letters are not significantly different at the 5% level (Duncan's Multiple Range Test).

Table 2. Summary of statistical analyses showing levels of significance for the various sunflower head and seed factors.

Factor	Variable: Planting (P)	Sampling (S)	Head area (A)	Interaction: P×S	P×A	S×A	P×S×A
Head diameter	**†	**	NA‡	**	NA	NA	NA
Head fresh weight	**	**	NA	**	NA	NA	NA
% Seed dry matter	**	**	**	**	**	**	**
Weight/seed	**	**	**	**	**	**	**
% Total oil	**	**	**	**	**	**	**
% Oleic acid	**	**	**	**	**	**	*
% Linoleic acid	**	**	**	**	**	**	*

† Significance levels—** and * denote 1 and 5% levels, respectively. Based on F-value determined by analysis of variance technique.
‡ Not applicable.

head weight (y) and head diameter (x) was $y = -619.9 + 5.87x$, with $r = 0.909$ ($P < 0.001$). Average head weights increased due to growth from the first to the fourth sampling, then decreased with each subsequent sampling due to moisture losses as the sunflower matured.

Seed Dry Matter Percent

Seed dry matter as a percent of seed fresh weight steadily increased from the first to the last sampling (Fig. 1). Sampling values averaged across all plantings and head zones were significantly different (Table 1). Dry matter percent was highest at the outer and lowest at the inner zone of the head. All differences were statistically significant. Average values (across samplings and head zones) were highest for the 18 July and lowest for the 1 August planting (Table 1). The low value for the 1 August planting resulted from slow development (Fig. 1) of the late-planted sunflower. Failure of seed to reach a maximum dry matter percentage for some plantings indicated that the seed had not become air dry, even though the seed was physiologically mature as suggested by data in subsequent sections.

Weight Per Seed

Average dry weight per seed significantly increased from the first to the eighth sampling, after which no further increases occurred (Table 1). Lack of significant differences among the last three samplings indicated that the sunflower had reached physiological maturity before the last sampling. For individual plantings, trends for seed weight (Fig. 2) were not as uniform as for dry matter percent (Fig. 1) because seed weight was strongly influenced by head diameters. In contrast, dry matter percent reflected seed development stage; therefore, dry matter percent increased rather uniformly regardless of head diameter and seed weight. Average seed weights were highest for the outer and lowest for the inner zones of the head. The differences were statistically significant (Table 1). Numerically, seed weight averaged highest for the 18

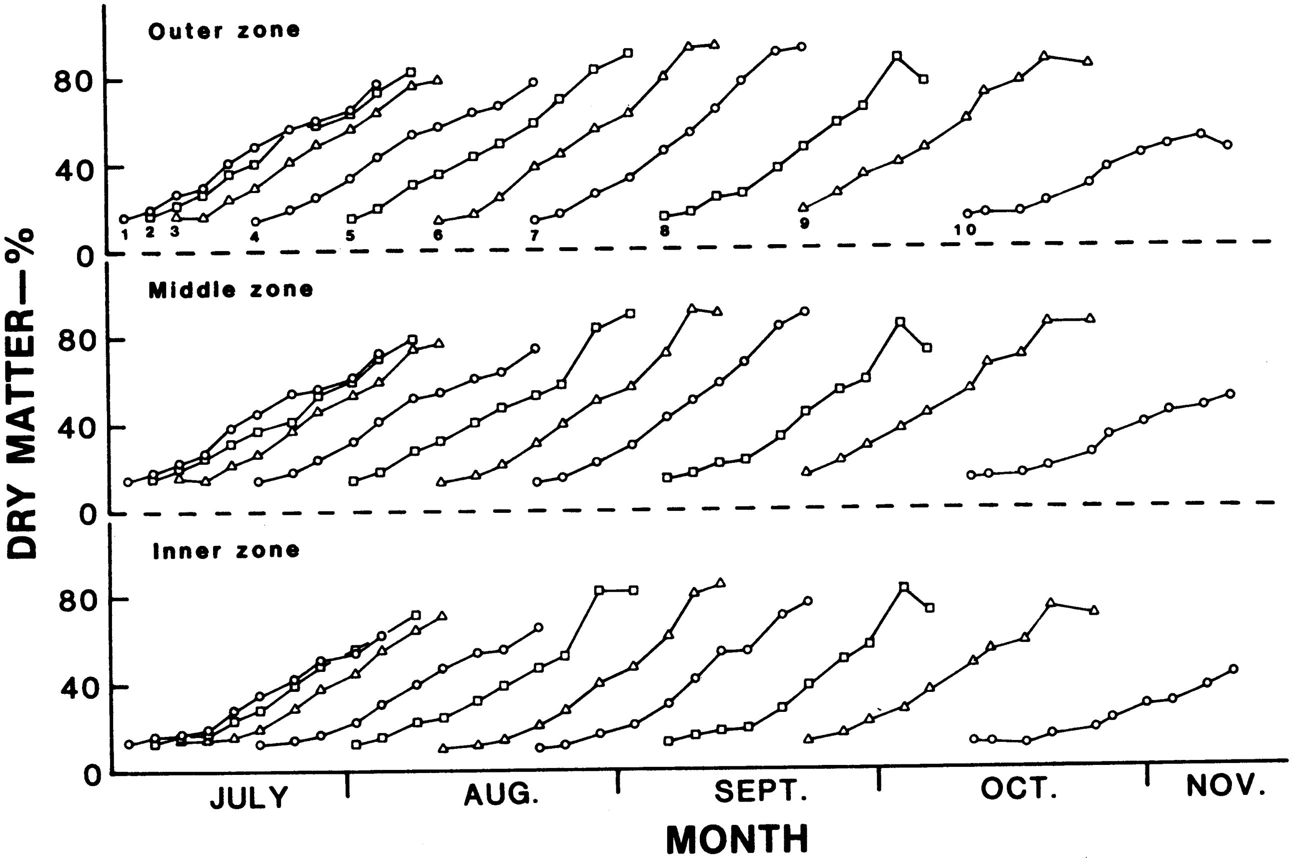

Fig. 1. Effect of planting, sampling, and head zone on seed dry matter. Numbers at lines for outer zone correspond to planting number (Table 1).

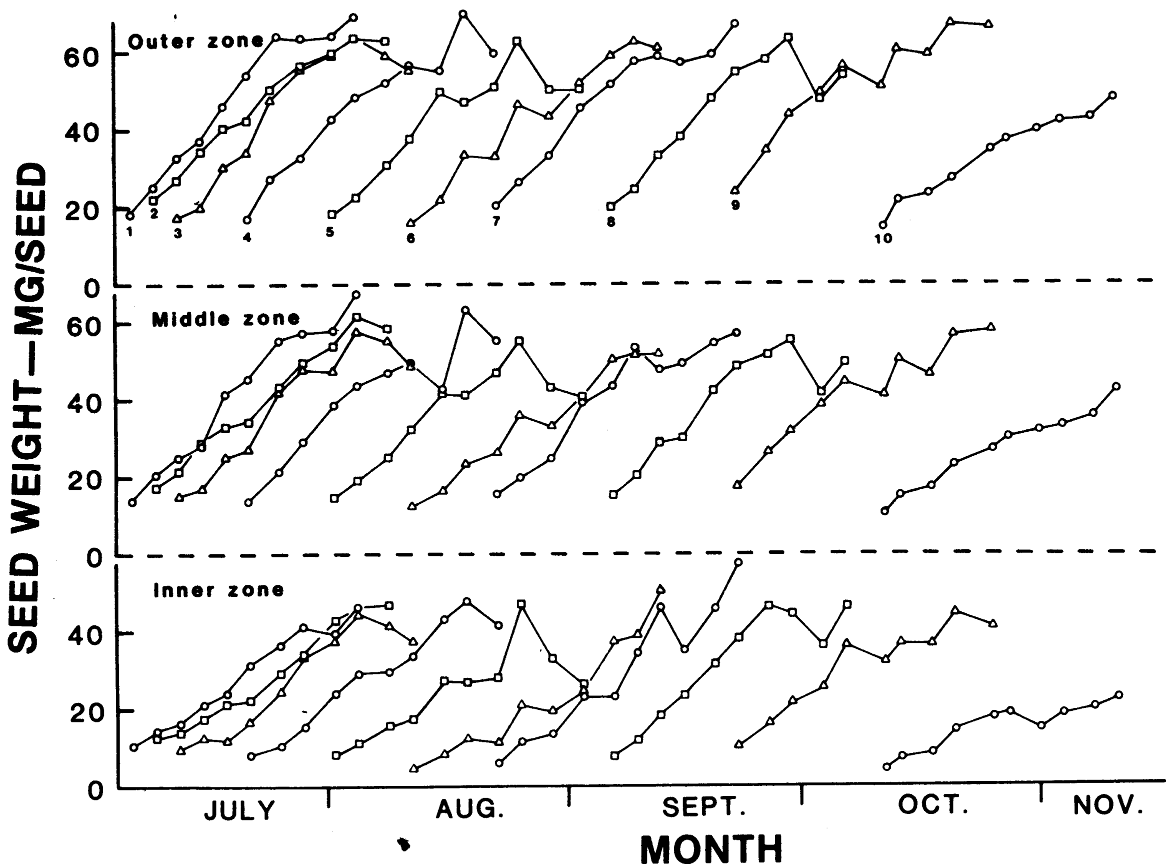

Fig. 2. Effect of planting, sampling, and head zone on seed weight. Numbers at lines for outer zone correspond to planting number (Table 1).

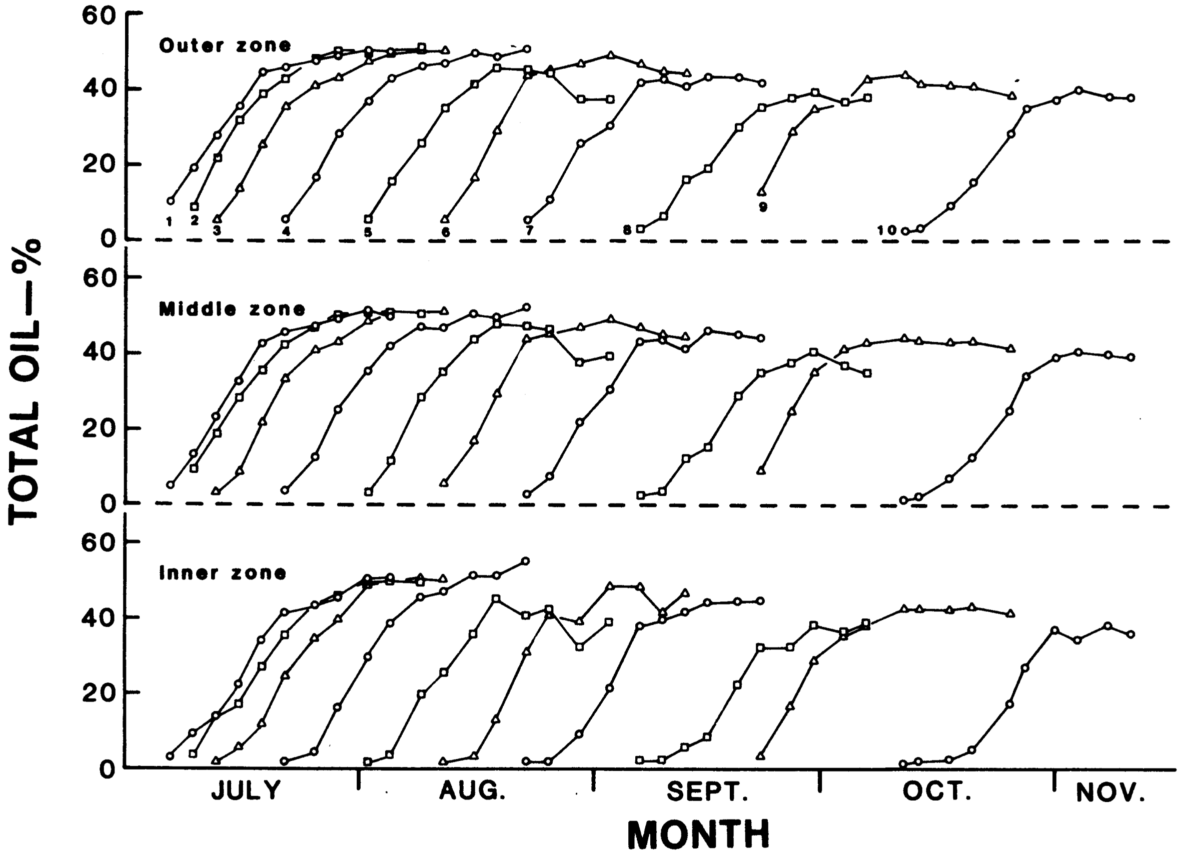

Fig. 3. Effect of planting, sampling, and head zone on total oil content. Numbers at lines for outer zone correspond to planting number (Table 1).

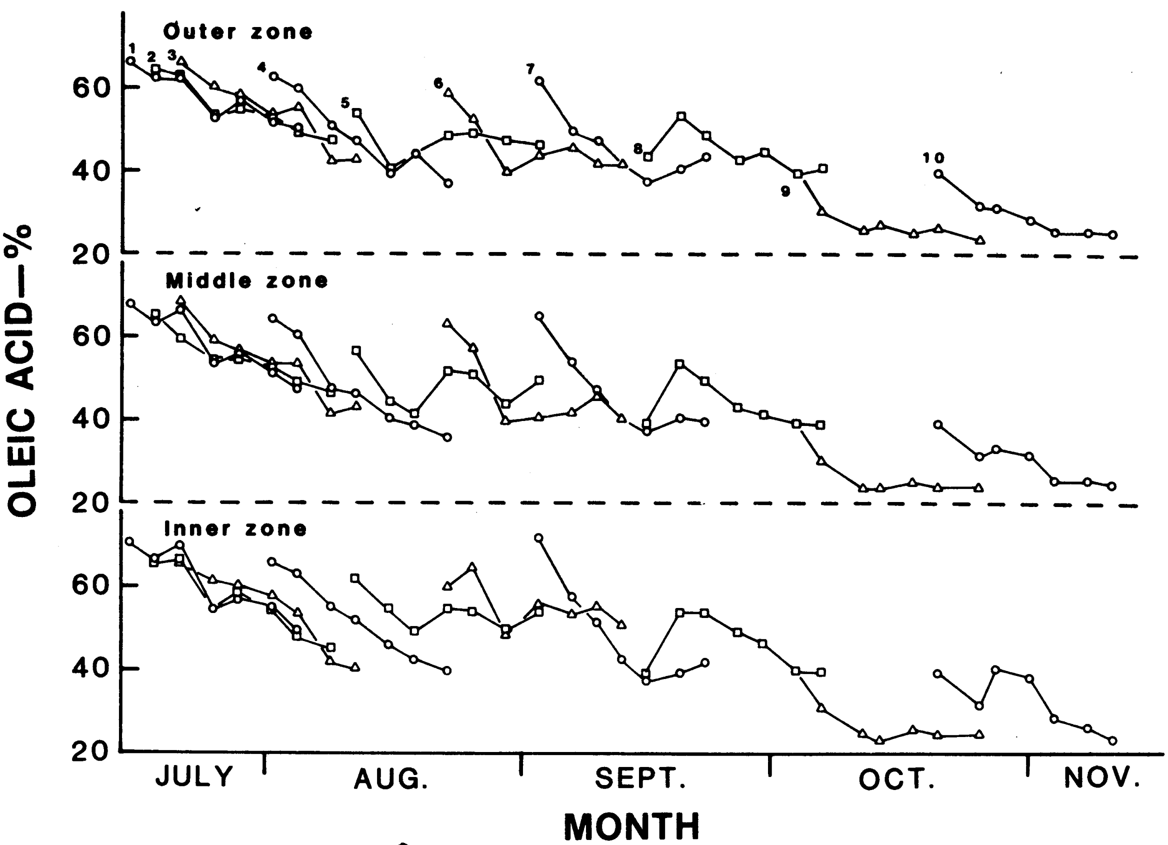

Fig. 4. Effect of planting, sampling, and head zone on oleic acid concentration of oil. Numbers at lines for outer zone correspond to planting number (Table 1).

July planting, but this value was not significantly different from values for some of the other plantings (Table 1).

Seed Oil Percent

Seed averaged only 4.3% oil at the first sampling, but increased to over 40% by the sixth sampling (Table 1). All differences due to sampling date were significant, except those for the last four samplings. Seed from the outer zone of the head reached a higher oil percent sooner than seed from the middle or inner zones (Fig. 3). On the average, seed from the inner zone reached its highest oil percent at the last sampling, at which time the oil percentages were similar for all zones. Although average oil percent differences were not significant for the last four samplings, continued increase in seed oil percent for the inner zone suggested continued seed development and oil production until the last sampling. However, data in Fig. 3 for the different plantings indicate that the maximum oil percent for seed in the inner zone was reached by the eighth or ninth sampling in most cases, suggesting that most oil had been produced by that time.

Oil percent averaged highest in seed from the second planting, but this value was not significantly different from those for the fourth and ninth plantings (Table 1). Although significantly different (Table 1), average oil percentages varied relatively little for the first through the sixth plantings, then decreased until the last planting for all zones of the head, except for the ninth sampling (Fig. 3). The oil percent was high at the first sampling for the ninth planting (Fig. 3), which suggests that the initial sampling was delayed. Sampling for this planting started 15 days after marking the plants, which was from 3 to 6 days later than for all previous plantings. However, the relatively high oil percent for the ninth planting was not entirely an effect of delayed initial sampling because oil percentages for the sixth through tenth sampling for this planting were higher than for the same samplings for the eighth and tenth plantings.

Oleic and Linoleic Acids

Data for oleic (Table 1, Fig. 4) and linoleic (Table 1) acid concentrations of oil from seed of the individual plantings were more variable than most other data, but general trends were evident. Oleic and linoleic acids were determined only for seed from the fourth

Table 3. Relationships among environmental factors and average changes per day in total oil content and oil composition between samplings for which the regression coefficients were statistically significant.

Factor	Equation	R	SE†
Total oil—%	y = −1.907 + 0.1426 (Max. T)‡	0.684**§	0.836
	y = 0.786 + 0.1108 (Min. T)	0.653**	0.869
	y = −0.563 + 0.1332 (Mean T)	0.688**	0.832
Total oil—mg/seed	y = −0.249 + 0.0392 (Max. T)	0.481**	0.394
	y = 0.493 + 0.0305 (Min. T)	0.460**	0.399
	y = 0.117 + 0.0368 (Mean T)	0.486**	0.393
Oleic acid—%	y = 5.295 + 0.1667 (Solar Rad.)‡ −0.0122 (Daylength)‡	0.425*	1.010
Oleic acid—mg/seed	y = −0.421 + 0.0318 (Solar Rad.)	0.356*	0.430
Linoleic acid—%	y = −7.273 − 0.2354 (Solar Rad.) + 0.0169 (Daylength)	−0.472*	1.237

† Standard error.
‡ Temperature in degrees C, solar radiation in MJ/m²/day, and daylength in minutes.
§ Significance levels—** and * denote 1 and 5% levels, respectively.

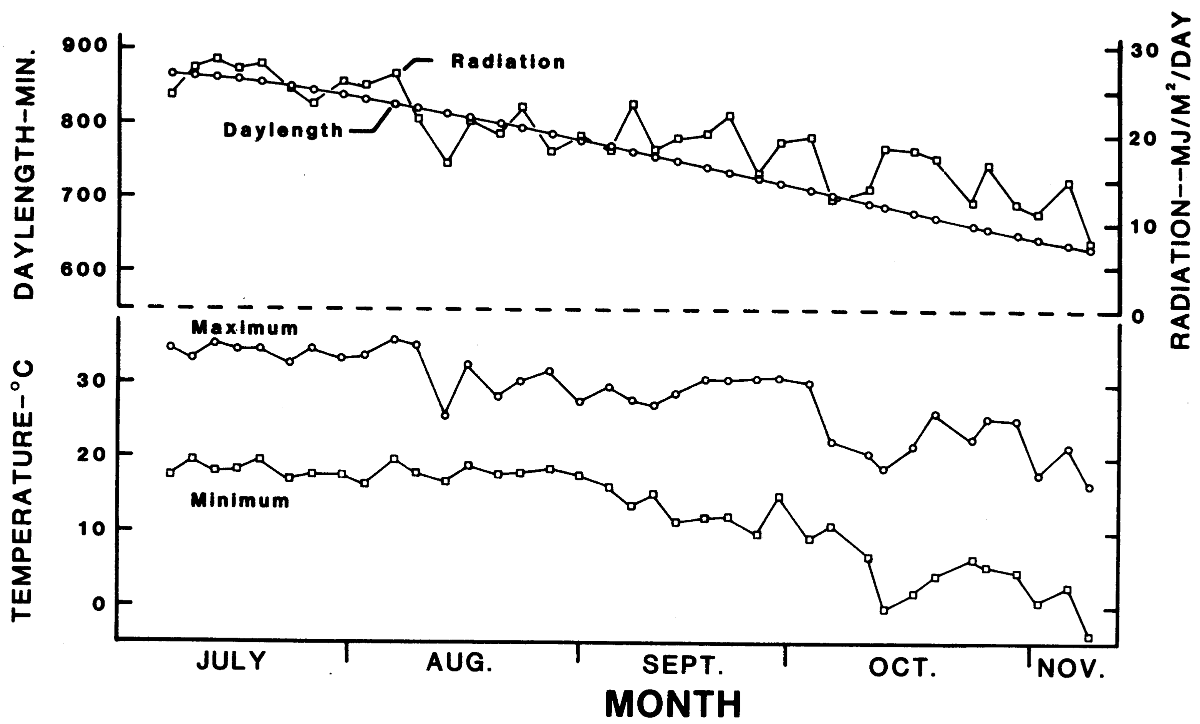

Fig. 5. Average maximum and minimum temperature, solar radiation, and daylength for periods between successive samplings from July to November 1977 at Bushland, Tex.

to tenth sampling. Seed obtained at earlier samplings had too little oil to be extracted by a hydraulic press that was used for oil extraction.

Oleic acid concentration generally was highest for the fourth sampling and decreased irregularly through the last sampling (Fig. 4). Converting our data to a weight per seed basis showed an initial increase, then a relatively constant value for the seventh through tenth sampling (Table 1). This was different from the results of Hopkins and Chisholm (1961) who showed that oleic acid on a weight per seed basis greatly increased from the first to last sampling.

Because oil from more mature seed had a lower oleic acid concentration than oil from less mature seed, oil from seed of the outer head zone had a lower average oleic acid concentration than that from seed of the inner zone (Table 1). Seed in the outer zone of a sunflower head are fertilized first and mature earlier than seed in inner zones. At the last sampling, oil from seed of all zones had similar oleic acid concentrations (Fig. 4). These data contradict the data of Zimmerman and Fick (1973), who reported a decrease in oleic acid concentration from the outer to the inner zone of mature heads of sunflower grown in North Dakota. Because of much lower seed weight, seed from the inner zone had much less oleic acid on a weight per seed basis (Table 1).

Average oleic acid concentration was highest in oil from seed of the first planting and usually decreased significantly for each successive planting (Table 1). The midpoint of samplings (19 July) for the first planting date corresponded closely with the date of mean maximum daily temperature (18 July) (Unger, 1980). Therefore, sunflower of later plantings matured during periods of progressively cooler average temperature (Fig. 5). Because oleic acid concentration reportedly is influenced by temperature during seed development (Canvin, 1965; Harris et al., 1978; Keefer et al., 1976; Robertson et al., 1979), the downward trend in oleic acid concentration for successive plantings after the first was as expected.

The trend for linoleic acid generally was opposite that for oleic acid (detailed data not shown). On a weight per seed basis, linoleic acid increased from the fourth to the last sampling (Table 1). This trend differed from that for oleic acid, for which a maximum occurred for the eighth sampling. These results support the hypothesis that oleic acid is transformed to linoleic acid in sunflower (Hopkins and Chisholm, 1961).

Environmental Effects

Multiple regression analyses showed that seed weight changes per day between samplings were not significantly affected by average daily air temperature (maximum, minimum, or mean), total and net solar radiation, or daylength between samplings. Average maximum and minimum temperatures, total solar radiation, and daylength between samplings are shown in Fig. 5. Changes in oil of seed, both on percent and weight per seed bases, were significantly related to maximum, minimum, and mean air temperature (Table 3). Mean temperature as the independent variable resulted in the highest correlation coefficient and the lowest standard error.

Changes per day in oleic and linoleic acid concentration of oil between samplings were significantly affected by total solar radiation and daylength, but air temperature and net solar radiation had no significant effect. The lack of response to temperature, which seemingly contradicts other reports (Harris et al., 1978; Keefer et al., 1976; Robertson et al., 1979), can be explained in two ways. First, we determined the changes per day between samplings in acid concentration of oil for seed from the different plantings and head zones as the seed developed and related these changes to average environment between the samplings. In other reports, the acid concentration of oil from mature seed was related to temperature during the development period. Effects of solar radiation and daylength were not reported. Second, maximum, minimum, and mean air temperature were significantly ($P < 0.01$) related to total solar radiation and daylength during our study. Presumably, this also occurred during the study conditions for the reports from other locations. In the other studies, acid concentrations were analyzed only with respect to temperature; however, the close relationship of acid concentrations to temperature possibly was secondary to the relationship between acid concentration and total solar radiation or daylength.

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